Note

Standard Operating Procedures (SOPs) for Research in Weed Science[1]

WILLIAM W. DONALD and PAUL H. SCHWARTZ[2]

Abstract. Standard operating procedures (SOPs) were developed for repetitive field research tasks to help ensure that instructions were complete and to provide consistency and continuity in the senior author's field research program. SOPs are explicit step-by-step instructions for carrying out experimental tasks that are components of experimental plans. SOPs are not the same as protocols for unique, new experimental plans. However, protocols may incorporate sequences of SOPs, if desired. SOPs are most useful for new workers and when research tasks need to be repeated infrequently in time (e.g., once every 6 mo or less per year). SOPs may help researchers enhance data accuracy, precision, and reproducibility as part of their own statistical quality control procedures. The authors' field-tested SOPs are available on diskette[3] for critical review, modification, and use by interested weed scientists.
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Introduction

The principles of statistical quality control[4] have been adopted by disciplines such as chemistry and engineering, and in manufacturing industries for improving research or manufactured product quality (3, 9). Taylor (11) reviewed statistical quality control for improving the accuracy, precision, and reproducibility of measurements in analytical chemistry. Taylor's authoritative book is an excellent introduction to statistical quality control in analytical chemistry, although other sources are available (1, 3, 4, 6, 7, 8, 9, 10).

Because quality control is a branch of statistics, its terminology and jargon differ from that used in everyday speech or that used in a legal sense by government regulatory agencies (5). For example, Taylor (11) defined quality as, "an estimation of acceptability or suitability for a given purpose of an object, item, or tangible or intangible thing." According to Taylor (11), quality control is, "The overall system of activities whose purpose is to control the quality of a product or service so that it meets the needs of users. The aim is to produce quality that is satisfactory, adequate, dependable, and economic."

Statistical quality control is not a formal part of the academic training in many scientific disciplines. This does not mean that research data generated without SOPs are not of acceptable quality for its intended use. The objective of this methodology note is to describe how SOPs might be used in planning and conducting weed science research.

Standard Operating Procedures (SOPs)

According to Taylor (11), an SOP is "a procedure adopted for repetitive use when performing a specific measurement or sampling operation. It may be a standard method or one developed by the user." Thus, SOPs often refer to commonly accepted, state-of-the-art published scientific or technical methods (e.g., 2), or manufacturer's instruction manuals.

SOPs describe procedures for doing repetitive tasks or measurements, but are not complete experimental plans or protocols in themselves. Well written SOPs contain explicit step-by-step instructions for carrying out component parts of larger experimental plans or protocols (11). SOPs may describe sampling, sample preparation, calibration, and measurement. They may also describe facilities, equipment, supplies, and chemicals that are needed, as well as specific sources of supply, if necessary. Sequences of SOPS may be referenced in plans when designing new experiments.

Published research methods may contain steps that are "common knowledge" in a scientific field, but do not convey sufficient instructions to technicians, graduate students, or temporary hourly workers assisting in conducting experimental procedures. SOPs may incorporate past ex-

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[2]Res. Agron., Cropping Systems and Water Quality Res. Unit., Agric. Res. Serv., U.S. Dep. Agric., 244 Agric. Engr., Univ. Missouri, Columbia, MO 65211 and Staff Scientist, Pesticide Research Staff Bldg. 1072, BARC-E, Beltsville, MD 20705.

[3]DOS formatted diskette in Wordperfect 5.1.

[4]The senior author's field SOPs and the following discussion of quality control were not written from the perspective of legal government regulatory requirements (5). Because the definitions of terms used are largely scientific definitions, some definitions may differ from purely regulatory, legal definitions.

perience to meet the individual researcher's needs. SOPs can include suggestions, based on experience, to correct problems that might arise over time. By explicitly including written suggestions for overcoming anticipated or past problems, SOPs help researchers and their assistants improve data reproducibility and help them refine their own research procedures.

Where appropriate, SOPs can include measurement requirements which set bounds or tolerances on data accuracy, precision, representativeness, comparability, and completeness (11). The researcher's requirements for measurement accuracy and precision should be based on the researcher's own past statistical performance defined in periodically updated quality control charts (11). Taylor (11) defined quality control charts as, "A graphical plot of test results with respect to time or sequence of measurement, together with limits [confidence intervals] within which they are expected to lie when the system is in a state of statistical control."

Usefulness of SOPs

The flow chart (Figure 1) is an example of how one might develop an effective SOP while planning and conducting research. The concept of individual researchers developing and using their own field SOPs in weed science may have the following potential advantages for conducting field research:

- SOPs may help document repetitive research methods.
- SOPs may help streamline the planning of experiments. When the same procedures will be used for several experiments, different SOPs may be arranged as a series of steps in experimental plans (10). SOPs eliminate the need to rewrite repetitive procedures for each new experiment, increasing efficiency and saving time.
- SOPs can supplement training and help better communicate research tasks to technicians, graduate students, and hourly workers. SOPs can enhance communication with trainees by providing a document from which serious discussion about procedural details can take place. Those training others to do research tasks also do not have to rely entirely on memory or word-of-mouth to communicate all procedures (10). SOPs help minimize the instructor's need to remember all procedural details or repeat themselves. After learning a demonstrated research task, SOPs can help assistants answer questions in the scientist's absence. This may save them time and help them avoid delaying research.
- SOPs can be used to help formally elicit feedback from assistants on ways to improve research procedures as part of a concerted team effort to identify causes for procedural flaws and improve data reproducibility (Figure 1). When newly written SOPs confuse assistants, it encourages researchers to clarify themselves. Feedback criticism of SOPs or suggestions by assistants can help speed completion of tasks, reduce research costs, or improve data reproducibility by increasing accuracy and precision.
- SOPs allow more detailed information to be conveyed than is possible verbally. SOPs may reference safety, health or environmental concerns, as well as sources of supply for ordering equipment, supplies, and chemicals, or information on the receipt, use, storage, and disposal of pesticides, hazardous chemicals, or radioisotopes.
- SOPs which include checklists can help technicians and others completely assemble what they will need to perform field research tasks before they start, eliminating unnecessary trips to and from research sites to retrieve forgotten supplies.
- SOPs which include data collection forms help define what specific data are to be collected by technicians and others, ahead of time. Self-explanatory, generic, fill-in forms can increase efficiency and save time. Data collection forms in a format similar to data-entry spreadsheets can help reduce transcription errors.
- SOPs can help to maintain research continuity over time, especially when research tasks are repeated infrequently (e.g., once every 6 mo or less per year). SOPs can increase the likelihood that all assistants follow researcher's procedures the same way each time (8). SOPs also make it less likely that the valuable research experience and insight of research assistants and technicians would be lost to the researcher if they were to leave.
- SOPs can help coordinate research efforts and prevent procedural errors when several people contribute separately to cooperative, coordinate research projects (10). SOPs can also help ensure that data reproducibility and variability are maintained consistently over time by all people contributing to team research projects.
- Written SOPs are much easier to critique in a timely fashion than verbal communication. Thus, SOPs can be used to more quickly reach group consensus on the adequacy of shared research procedures when planning cooperative research projects. SOPs can be used to help standardize repetitive research procedures used by co-

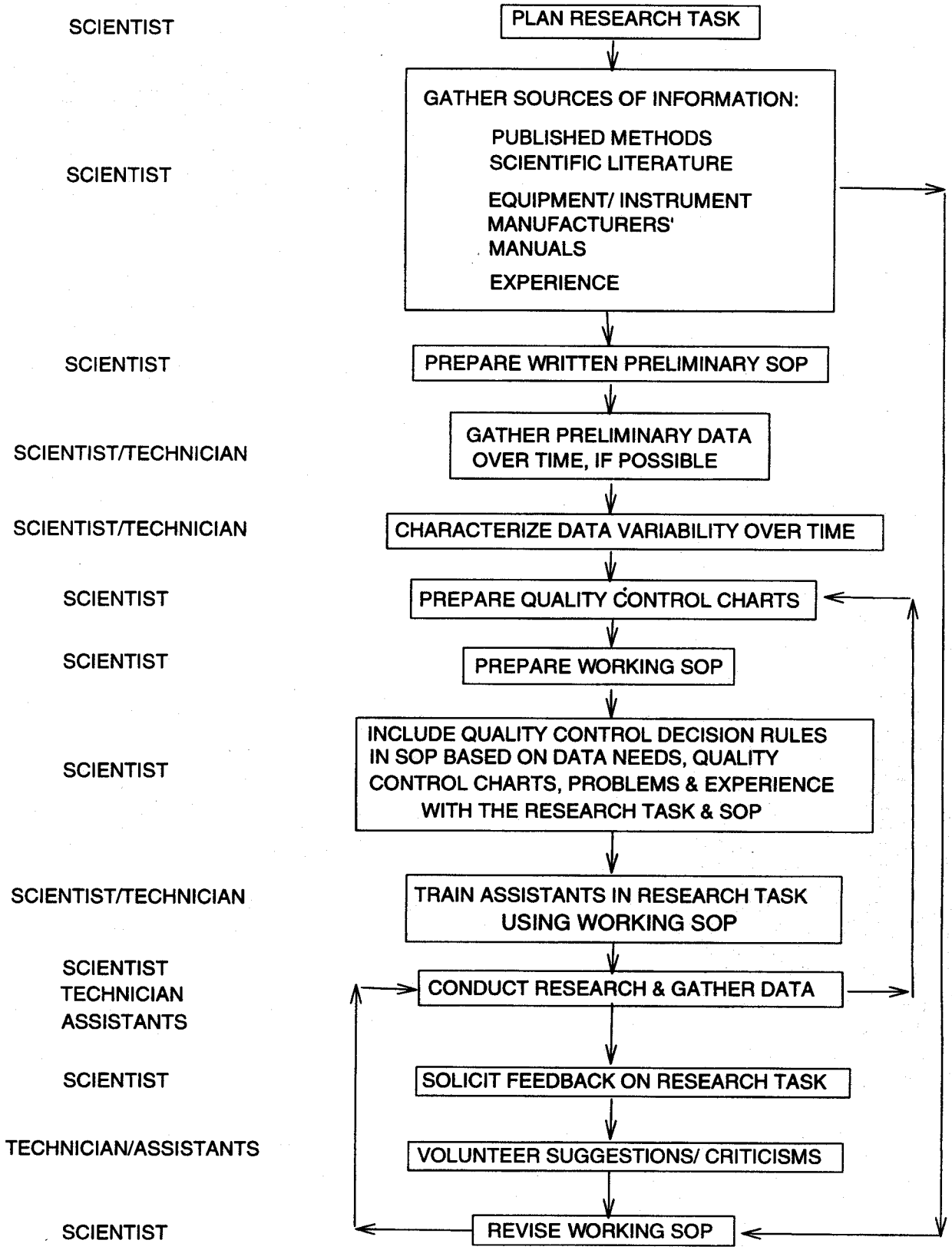

Figure 1. Flow chart of proposed iterative processes used in preparing SOPs.

Table 1. Major topics from the table of contents for standard operating procedures for repetitive field research tasks.

Number	Description
1.0	OVERVIEW OF STANDARD OPERATING PROCEDURES
2.0	PERSONNEL
3.0	FACILITIES
4.0	EXPERIMENTAL DESIGN, EXPERIMENT PLANNING, STATISTICAL ANALYSIS, AND DATA COLLECTION AND FORMS
5.0	FIELD EQUIPMENT, INSTRUMENT, AND GAUGE MAINTENANCE, CALIBRATION, AND OPERATION
6.0	FIELD OPERATIONS FOR CROP MANAGEMENT AND CULTURE: USE OF FIELD EQUIPMENT
7.0	PESTICIDE APPLICATION AND CLEANUP
8.0	SOIL SAMPLING
9.0	COLLECTION OF DATA
10.0	PESTICIDE AND CHEMICAL RECEIPT, HANDLING, AND DISPOSAL
11.0	SAFETY AND HEALTH PROCEDURES

Table 2. Examples of topics for which standard operating procedures were prepared.

Number	Description
9.0	COLLECTION OF DATA
9.1	Collection and recording of data from monitoring devices
9.2	PLANT/WEED MEASUREMENTS
9.2.a	Weed name abbreviations
9.2.b	Weed control rating and phytotoxicity data
9.2.c	Plant density determination (weeds and crops)
9.2.d	Dry weight determination for plant materials
9.2.e	Weed seedling identification for demographic study
9.2.f	Gathering soil cores for weed seed determination
9.2.g	Extraction of weed seed from soil
9.2.h	Use of the Cannon Xapshot and RC-570 video camera for capturing field images of plants for estimates of projected weed cover.
9.2.i	Use of Computer Eyes digitizer
9.2.j	Use of SV-PC digitizer
9.2.k	Use of MOCHA image analysis software for processing of video images
9.2.l	Mapping weed distribution
9.3	CROP MEASUREMENTS
9.3.a	Crop injury
9.3.b	Determination of straw residue on soil surface
9.3.c	Crop phenological (growth) stages
9.3.d	Gathering and processing crop yields for small plot research
9.3.e	Hand harvesting, threshing, cleaning and processing (weighing and moisture content) corn
9.3.f	Hand harvesting, threshing, cleaning and processing (weighing and moisture content) soybeans

operative researchers after negotiation and mutual agreement. Commonly accepted generic SOPs could facilitate database generation and sharing of large data sets.

- Written SOPs can be referenced in research grant proposals and may help improve the professional image and credibility of weed scientists with other scientific disciplines, potentially enhancing success in acquiring research grants.

SOPs may have several potential disadvantages:

- SOPs can be time consuming to write and periodically update, especially if critical feedback from others is solicited and used.
- SOPs may not always be written with enough flexibility to consider unexpected problems, typically encountered in field research. However, once problems are encountered and overcome, that experience can be readily incorporated into SOPs so that it is passed on to all participants in research over time.
- SOPs may not be needed for experimental procedures that will be used only once or a few times. SOPs may not be appropriate for "one-of-a-kind" or exploratory experiments answering unique or very case-specific research questions. Experimental notes may suffice.

Most books on scientific methods concern laboratory methods, not field research methods. Individual field researchers have been left to create their own SOPs for field research methods, a time consuming task at best.

The senior author developed SOPs for repetitive field research tasks. The SOPs were modified and formatted based on documentation initially written by Dr. Paul Schwartz for the USDA ARS's IR-4 program. The authors will make their field SOPs available on diskette[3] for release to interested researchers who might wish to modify, adapt, or use them for their own field research. Major topics that were included in the table of contents for the author's field SOPs are presented in outline form (Table 1). Table 2 lists examples of detailed field SOPs under the major topic of data collection. Field SOPs were periodically reviewed and updated according to the flowchart (Figure 1) to document problems and ways to overcome them, improve clarity, or progressively improve data reproducibility. Interested researchers can modify and expand these SOPs for their own use. Because the authors recognize that others may have different or better research methods, the authors welcome critical reevaluation and suggestions for improving their SOPs. Some field research methods have been arbitrarily adopted based on convenience and there may be better alternative ways of achieving the same ends.

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